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OPTIMIZATION OF CASTING PARAMETERS USING TAGUCHI METHOD

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ABSTRACT

Casting is a manufacturing process used in industries for mass production in which materials in molten state are poured in a mold cavity to solidify. A foundry's performance should be high in terms of production with minimum defects. Systematic analysis and identification of sources of defects are essential for successful manufacturing. Various casting parameters like moisture content, permeability, pouring temperature, green compressive strength, mold hardness number and clay percentage affect the casting quality. This paper discusses the influence of various casting parameters on the quality of casting. The prominent parameters (moisture percentage, green compressive strength, mold hardness number) were selected on the basis of comparative study of research papers. Weight percentage was selected as the response variable to obtain best results with minimum possible cost of experimentation. To optimize the selected parameters, Taguchi optimization technique was used by implementing L9 orthogonal array and optimum values of parameters were obtained by Minitab software analysis. The results show that weight percentage is minimal at certain levels and these were verified practically by implementing in foundry, which resulted in significant improvement in quality of casting.

***KEYWORDS**: Casting Defects, Implementation, Minitab; Optimization, Sand Casting & Taguchi Method*

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Original Article

INTRODUCTION

Casting is an engineering manufacturing process, generally used for mass production in which materials in a molten state are poured into a mold, where they are solidify. Defects from the casting process leads to loss in production which result in the shutdown of many small-scale foundries. Casting quality is influenced by various sand process parameters and their levels. For controlling process parameters, one must have the knowledge about the effect of sand parameters on casting and the causes of various defects.

Gray iron castings are readily available in all industrial areas and can be produced in foundries representing comparatively modest investments. It has the lowest pouring temperature of the ferrous metals, which is reflected in its high fluidity and its ability to be casted into intricate shapes. Gray iron has excellent machining qualities. It has acceptable ductility, tensile strength, and yield strength and impact resistance for most of the applications. Gray iron is also excellent in damping vibrations, making it ideal for machinery base and household applications. Gray iron has high thermal conductivity which enables it to move heat more easily through the metal. The common applications of gray iron includes: gears, hydraulic components, automotive suspension components etc.

The correct identification of casting defects in the initial stage is essential for taking remedial action. The quality and yield of casting can be improved by Taguchi method. This method is adopted to achieve optimized output with minimum number of experiments. If we have an experiment having 3 factors at 3 levels, then the possible numbers of experiments are 27 and the result of experiments will be 100% accurate. In comparison to the above method, Taguchi orthogonal array makes a list of 9 experiments in an order that covers all the factors. These experiments will give 99.96% accurate results.

METHODOLOGY

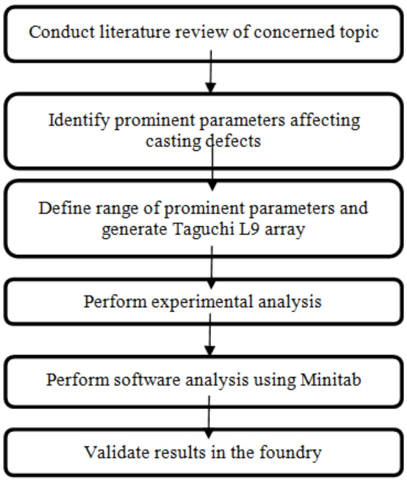

Figure 1

REVIEW OF LITERATURE

(Chandran. R. M)[4] et al. practiced the use of Taguchi method to minimize the defects in casting process. The author designated a L9 orthogonal array for process parameters moisture content (%), green strength (g/cm^2), sand particle size (AFS) and mold hardness number (Nu) having three levels ranging between 3-4.3, 1200-1800, 50-55 and 50-80 respectively. For lower range the better signal to noise ratio and defect percentage were used as the response variable and it was seen that at moisture 3.8%, green strength 1400 g/cm^2, sand particle size 50 and mold hardness 75, the results were optimum.

(Upadhye R. A.) [5] et al. implemented Taguchi and ANOVA (Analysis of Variance) technique to reduce the casting defects in a foundry. The author advanced by selecting parameters such as moisture (%), sand particle size (AFS), green compressive strength (g/cm2), mold hardness, permeability and pouring temperature for optimization at three levels each ranging from 3.5-4, 50-55, 900-1200, 50-80, 150-220 and 1300-1420 respectively. Defect percentage was selected as the response variable and lower the better signal to noise ratio was selected. The author observed that the best results were obtained when the levels of parameters were moisture 3.5, sand particle size 55, green compressive strength 900, mold hardness 80, permeability 185 and pouring temperature 1420.

(Raghupathy) [6] et al. optimized the casting process using Box Behnken design and response surface methodology. The author designed a matrix based on Box Behnken design using parameters clay content (%), moisture content (%), and mold hardness (Kg/cm^2) at three levels limiting between 2-4, 3-5 and 5-6 respectively. The defective components were counted and this theory was used as response variable and minimised it by using ANOVA technique.

The work was finished by concluding that at clay 2%, moisture 3.87% to 4% and mold hardness 5.21 to 5.45 Kg/cm^2, the defects were minimal.

(Patil) [7] et al. demonstrated the use of Taguchi method to optimize casting parameters. The author considered mold hardness number Nu (Number), moisture percentage (%), permeability (Nu) and green compressive strength (g/cm2) at the intervals 80-90, 4.75-5.3, 105-135 and 1200-1300 respectively for the formation of L9 orthogonal array. Lower the better type signal to noise ratio was adopted for rejection percentage as the response variable. It was found that for rejection percentage to be minimal, the values for mold hardness, moisture, permeability and green compressive strength were 90, 4.47, 135 and 1400.

(Kumar P) [8] et al. imposed Taguchi method to reduce casting defects in foundry. The author continued by selecting parameters such as compressive strength (g/cm^2), moisture content (%), permeability number (Nu) and mold harness number (Nu) corresponding to three levels ranging from 1000-1200, 3-4, 140-90, 85-95. Lower the better signal to noise ratio was adopted for rejection percentage as response variable. It was summed up that the optimum values of parameters were compression strength 1100, moisture 4, permeability number 190 and mold hardness number 90.

(Upadhye R.) [9] et al. proposed ANOVA and Taguchi method for optimization of sand casting process parameters. The author preferred parameters moisture (%), sand particle size (AFS), green compressive strength (g/cm^2), mold hardness (Nu), permeability (Nu), pouring temperature (˚C), pouring time (sec) and pressure (MPa) at three levels ranging between 3.5-4.0, 5.-55, 900-1200, 50-80, 150-220, 1300-1420, 20-28 and 1.5-2.5 respectively. Defect percentage was proposed as the response variable and lower the better signal to noise ratio was chose. The author obtained results which stated that the optimum conditions occurred at moisture 3.5, green compressive strength 900, permeability 185 and pouring temperature 1420.

(Kumar. M) [10] et al. produced work on implementing Taguchi method to optimize casting process. The author aimed at creating a L9 orthogonal array with parameters compression strength (g/cm^2), moisture content (%), permeability number (Nu) and mold hardness number (Nu) ranging between 1000-1300, 3.2-4.0, 140-190 and 85-95 at three levels. It was proposed that defect percentage should be taken as response variable for smaller the better signal to noise ratio. The author computed that at compression strength 1300, moisture 3.5, permeability number 163 and mold hardness number 95 the results were optimum.

(Kumar D.)[11] et al. studied the process improvement of casting processes using six sigma, ANOVA and Taguchi techniques. The author conducted study and advanced by selecting parameters such as moisture content (%), green strength (g/cm2), pouring temperature (˚C), mold hardness number (Nu) and compactibility (Nu) and designed an L18 orthogonal array with three levels ranging between 3.8-4.8, 130-150, 1360-1440, 172-1995, 35-40 and 75-90. Defect percentage was taken as the response variable and lower the better criteria were used. It was concluded that for minimum defect percentage the values of process parameters should be moisture 3.8, green strength 1995, pouring temperature 1440, mold hardness 83 and compactibility 40.

PROMINENT PARAMETERS, THEIR LEVELS AND ORTHOGONAL ARRAY

On the basis of comparative study of the above mentioned papers, the parameters were organised and their occurrence in the research papers were presented in a graphical representation. Figure 1 shows the number of times a selected parameter was prominent, based on the research conducted by the authors. It can be seen that moisture content,

green compressive strength and mold hardness number were the most prominent parameters.

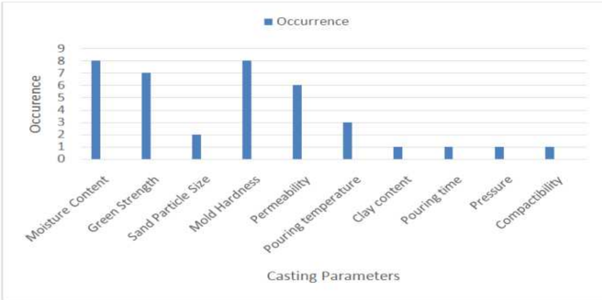

Figure 1: Occurrence of Parameters

Clearly, moisture content, green compressive strength and mold hardness number were the most prominent parameters & hence are selected in the study of this paper as prominent parameters. Figure 2 shows the graphical representation of the optimum values as identified in the research papers taken for the comparative study.

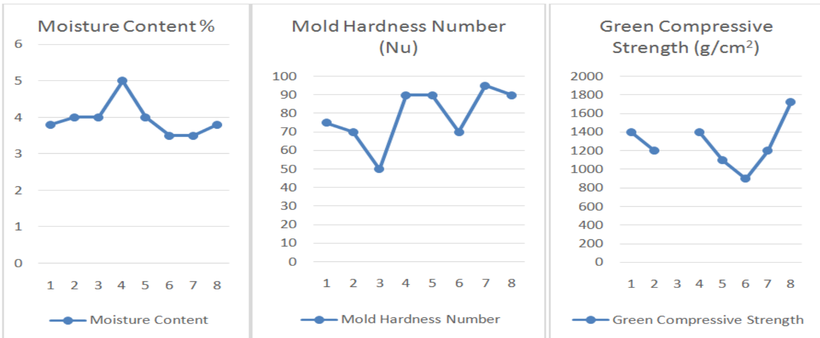

Figure 2: Optimum Values as Identified in the Research Papers

The prominent parameters moisture content, mold hardness number and green compressive strength were varied at three levels as shown in the Table 1 and the experiments were performed according to the Taguchi L9 orthogonal array as shown in the Table 2, in order to obtain the optimum values of the selected parameters.

Table 1: Levels of Prominent Casting Parameters

Parameter	Range	Level 1	Level 2	Level 3
Moisture Content (%)	3.5-4.0	3.5	3.75	4.0
Green Compressive Strength (g/cm^2)	1100-1300	1100	1200	1300
Mold Hardness Number (Nu)	70-90	70	80	90

Table 2: Design of L9 Array

Exp No.	Moisture (%)	Green Compressive Strength (g/cm^2)	Mold Hardness Number (Nu)
1	3.5	1100	70
2	3.5	1200	80
3	3.5	1300	90
4	3.75	1100	80
5	3.75	1200	90
6	3.75	1300	70
7	4.0	1100	90
8	4.0	1200	70
9	4.0	1300	80

EXPERIMENTATION

Shakti Foundry and Engg. Co. is a small-scale foundry situated in Bahadurgarh, Haryana, India which produces sand castings. The main casting products are cast iron pulleys, couplings and other cylindrical rotating elements. A cold blast cupola furnace of 27” internal diameter is used to produce around 120-130 tonnes of good casting every month.

The major steps in the production are shown in the Figure 3 and briefed below:

- **Mold sand preparation:** Fresh sand is mixed with bentonite powder, water and other additives in muller to make molding sand.
- **Molding:** The mold sand is rammed manually or by machines to prepare the mold. The cope and drag of the mold are assembled together to prepare the complete mold.
- **Charging:** Charge includes pig iron, scrap, limestone, manganese, coke and foundry returns that are weighed and charged in the cupola furnace for melting.
- **Pouring:** After melting, the molten metal is transferred into ladle and poured manually into molds.
- **Knock out:** The molds are left to cool down for a certain time after which the castings are knocked out from the mold either manually or through machines.
- **Finishing:** The finishing operation involves the removal of runner and riser, shot blasting and grinding of casting.

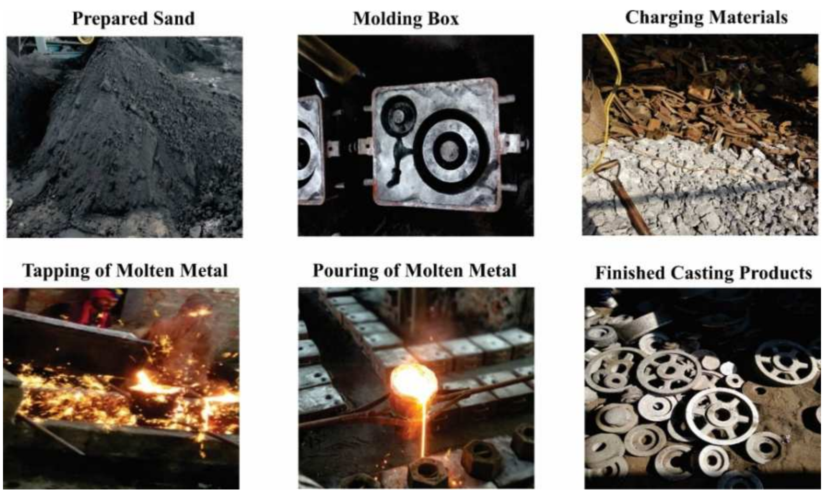

Figure 3: Steps Involved in Casting Process

Sand Testing

The molding sand was tested for its moisture, green compressive strength and mold hardness. Sand Testing is necessary to vary the prominent parameters and production of the castings as per the selected parameters.

Testing for Moisture Content

For measuring the moisture of the molding sand, an instrument called Rapid Moisture Tester was used. A Rapid Moisture Tester measures an intermediate variable and then converts it to moisture content. The purpose of this test is to measure the moisture content quickly, without having to wait for the moisture to evaporate. Figure 4 shows a Rapid Moisture Tester and Figure 5 shows a measuring scale to measure the moisture content.

Figure 4: Rapid Moisture Tester **Figure 5: Measuring Scale**

Testing of Green Compressive Strength

Green Compressive Strength refers to the stress required to rapture the sand specimen under compressive loading. The sand specimen is created and is immediately put on the strength testing machine and the force required to cause the compression failure is determined. Figure 6 shows a Strength Testing Machine and Figure 7 shows a Sand Rammer for creating the sand specimen.

Figure 6: Strength Testing Machine **Figure 7: Sand Rammer**

Testing of Mold Hardness

In Mold Hardness Test, a ball is pushed into the mold surface to measure the pushback resistance. A mold hardness tester is used to show the penetration of the ball -the softer the mold, the greater the penetration. The depth of indentation can be directly measured on the scale which shows units from 0-100.

The above mentioned methods were used to measure and vary the sand parameters for the construction of the sand molds and carry out the experimental analysis.

Values of Parameters Prior to Experimentation

The range of green sand casting parameters being controlled or monitored by Shakti foundry prior to experimentation was observed. The values of these parameters are listed as:

- The moisture % was found to vary between 3.5%-3.75%.
- Mold hardness number was being monitored but not controlled.

- Green compressive strength was found to vary between 1100 to 1300 g/cm^2.
- Compactibility % was found to vary between 38% and 42%.
- Permeability number was found to be greater than 150.

WEIGHT ANALYSIS

To obtain the theoretical weight, the volume of the sample was multiplied with the density of gray cast iron. Experimental analysis was conducted on the basis of orthogonal array to know the deviation of obtained value from the desired value.

Theoretical weight = Volume × Density

$= (1.79\times10^{-5}\, m^3) \times (7.20\times10^3\ Kg/m^3)$

= 128.88 grams

Figure 8 shows the casting of different samples according to the Taguchi L9 orthogonal array and Table 3 shows the orthogonal array along with the calculated weight error percentage.

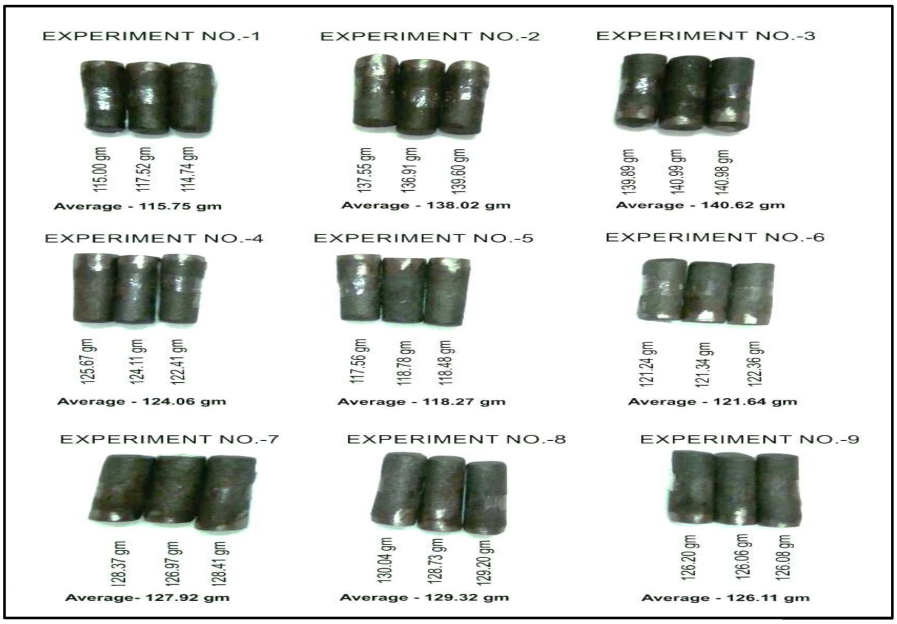

Figure 8: Average Weight and Weight Error % of Samples for Each Experiment

Table 3: L9 Array with Experimental Results

Experiment No.	Moisture (%)	G. C. S. (g/cm^2)	Mold Hardness (Nu)	Weight Error (%)
1	3.5	1100	70	10.19
2	3.5	1200	80	7.09
3	3.5	1300	90	9.11
4	3.75	1100	80	3.74
5	3.75	1200	90	8.23
6	3.75	1300	70	5.63
7	4.0	1100	90	0.74
8	4.0	1200	70	0.34
9	4.0	1300	80	2.15

SOFTWARE ANALYSIS

Figure 9 shows Minitab analysis for lower the better SN (Signal to Noise) ratio with error % as the response variable. The software generated SN ratios for each of the 9 experiments. The experiment with highest SN ratio in the table shows the most favourable out of the 9 experiments performed. Clearly experiment 1 is the least favourable with SNR (Signal to Noise Ratio) = -20.1635 and experiment 8 is the most favourable with SNR = 9.3704 out of the nine experiments performed.

	Moisture %	GCS	Mold hardness number	Error %	SNRA1
1	3.50	1100	70	10.19	-20.1635
2	3.50	1200	80	7.09	-17.0129
3	3.50	1300	90	9.11	-19.1904
4	3.75	1100	80	3.74	-11.4574
5	3.75	1200	90	8.23	-18.3080
6	3.75	1300	70	5.63	-15.0102
7	4.00	1100	90	0.74	2.6154
8	4.00	1200	70	0.34	9.3704
9	4.00	1300	80	2.15	-6.6488

Figure 9: Orthogonal Array and Resulting SN Values

Figure 10 shows the Minitab analysis for determining the ranks of the selected parameters. The parameter with the highest delta value is the most dominant. Clearly the rank for moisture % is 1st, G. C. S. 2nd and mold hardness number 3rd. Hence moisture % is the most dominant factor in minimizing error %, followed by G. C. S. and mold hardness number.

Response Table for Signal to Noise Ratios
Smaller is better

Level	Moisture %	GCS	Mold hardness number
1	-18.789	-9.669	-8.601
2	-14.925	-8.650	-11.706
3	1.779	-13.616	-11.628
Delta	20.568	4.966	3.105
Rank	1	2	3

Figure 10: Response Table for SN Ratio

Figure 11 shows the Minitab main effects plot for lower the better SN ratio with error % as the response variable. The level at which SN ratio is highest for each parameter is the optimum level for best results for corresponding parameter. Clearly the SN ratio is maximum for moisture at 4 %, G. C. S. at 1200 g/cm^2 and mold harness number 70 Nu.

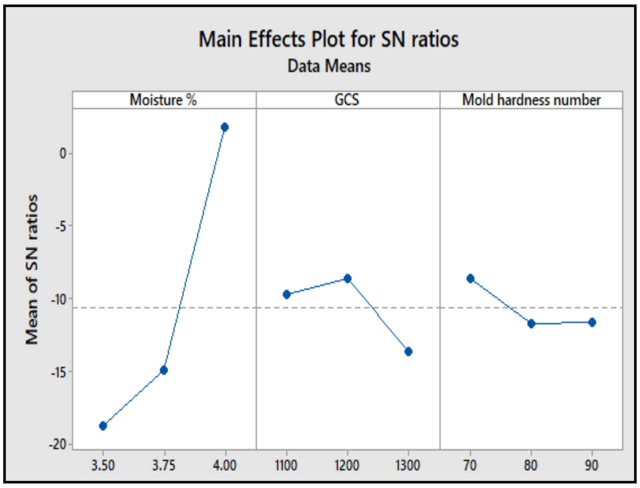

Figure 11: Graph of SN Values

CONCLUSIONS

On the basis of experimental and software analysis, the following conclusions were observed.

The ranking of different factors is in the following order:

- Moisture %
- Green Compressive Strength
- Mold Hardness Number

The following are the optimum values as obtained from analysis in Minitab software:

- Moisture – 4% (level3)
- Green Compression Strength – 1200 g/cm^2 (level 2)
- Mold Hardness Number – 70 Nu (level 1)

Implementation of Results

The verification of the results was carried out by implementing the optimum values of sand parameters in preparation of molds at Shakti foundry. A taper lock pulley, one of the prime products being manufactured was taken for the verification of results. For validation of the analysis, the results were compared between the existing parameters being used for the preparation of molds and the optimum parameters found out by using Taguchi analysis. Figure 12 shows the taper lock pulley and Figure 13 shows the software model of the pulley with dimensions.

Figure 12: Taper Lock Pulley

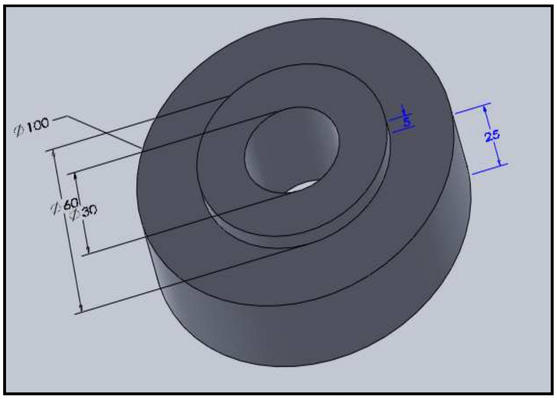

Figure 13: Dimensions of Taper Lock Pulley

Volume of taper lock pulley = 0.18928096 m^3

Density of Cast Iron = 7.2×10^3 Kg/m^3

Theoretical weight of the pulley = **1.362 Kg**

Figure 14 and Figure 15 show the weight of pulley with existing parameters of the foundry and optimum values obtained from analysis respectively.

Figure 14: Weight with Existing Parameters

Figure 15: Weight with Optimum Parameters

The actual weight of the pulley with existing parameters :

Theoretical weight = 1.362 Kg

Actual weight = 1.258 Kg

Error % = **7.69 %**

The actual weight of the pulley with the optimum levels of parameters :

Theoretical weight = 1.362 Kg

Actual weight = 1.3263 Kg

Error % = **2.70 %**

As noted, the error % has been reduced from 7.69 % to 2.70 % in the case when the pulley was manufactured with the resulting parameters found out by using the Taguchi analysis. Hence the results of the experimental analysis have been validated and verified.

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